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THERMONUCLEAR STATUS REPORT (U)

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ATOMIC WEAPON DATA
SIGMA CATEGORY 1

PART 1

STATUS OF THERMONUCLEAR DEVELOPMENT

RESTRICTED DATA
This document contains restricted data as defined in the Atomic Energy Act of 1946.

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PART 2

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EXCLUDED FROM AUTOMATIC DOWNGRADING AND DECLASSIFICATION

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DOD DIRECTIVE 5210.2 APPLIES

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August 1950

PART I

STATUS OF THERMONUCLEAR DEVELOPMENT

Prepared by

Edward Teller and John Wheeler

1. INTRODUCTION

When it was decided in February, 1950, to intensify work on a hydrogen bomb, it was not known whether such a weapon would prove feasible. In order to make the most effective use of the manpower available in the laboratory and to accelerate simultaneously the many necessary parallel lines of development, it was decided to direct the major effort toward an early experimental test of the thermonuclear principle. Such a test is now scheduled for the spring of 1951. The preparations for this test have required the solution of many experimental and theoretical problems which will also be needed for later stages in the development of thermonuclear weapons. A detailed report on this phase of the work is, however, not deemed advisable at the present time, since such a report will be more appropriate and informative after the results of the test have been evaluated.

The major purpose of next spring's test is to determine the conditions necessary for the ignition of a mixture of deuterium and tritium. The most important problem then remaining in the development of a hydrogen bomb will be to determine whether a flame will propagate down a cylinder of pure deuterium, and if so, how much tritium is

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needed to set it off. Some theoretical work directed toward these difficult problems has been carried out, within the severe limits set by insufficient manpower. There is some hope of faster progress after completion of the high speed computing machines now under construction. Other types of thermonuclear weapons have also been considered. As of August 1950 it is still impossible to say whether or not any thermonuclear weapon is feasible or economically sensible.

Stimulated by inquiries from the General Advisory Committee to the AEC, the following report has been prepared, dealing primarily with the long range questions of possibility and practicality. Investigation of most of these questions is in a preliminary state. This report is intended to summarize the information which has been gained.

The main points of investigation have been the following:

(1) Added insight has been gained into the burning of deuterium and deuterium-tritium mixtures.

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(2) The principal outstanding issue on physical possibility of a super is whether a cylinder of deuterium once ignited at one end will continue to burn down its length. This problem had been answered by a probable "yes" in 1947 (LA-666). Changes in cross sections and in the

analysis of the inverse Compton effect in the meantime have weakened this conclusion. It is hoped that this question can be settled with the help of the new Princeton and Los Alamos high speed electronic computers.

(3) Designs have been made for three devices, any one of which should be suitable for an intermediate thermonuclear test in the spring of 1951.

The theoretical design work on this and the other two alternative thermonuclear devices has been carried out by about half a dozen members of T Division. The associated engineering design, special fission bomb development work, and preparation of measuring devices have taken a substantial fraction of the effort of the whole laboratory.

(4) The measuring devices for the spring test have been analyzed in considerable detail and a substantial fraction of the experimental physics development on them has been carried through. Their purpose

is to find out how much tritium has burned, how quickly it burned, and what were the conditions of temperature and pressure to which it was subject. The tests in the spring of 1951 are counted upon not only to tell something about the burning of DT but also to test the measuring devices themselves with a view to future use of the more promising ones in any subsequent thermonuclear tests.

(5) Some thought has been given from time to time to the physics of devices which combine the fission reaction of the conventional bomb with the fusion reaction basic to the deuterium super. These reactions are combined in a so-called "fission booster," one of the three intermediate thermonuclear devices designed for possible use in the March 1951 tests.

The greater portion of the following report is devoted to items (1) and (2) above, even though only a minor portion of the laboratory effort could be devoted to these important issues. The calculations made up to date are so idealized that they permit no definite conclusion about the burning of a deuterium cylinder although they do clearly indicate that a sufficient mass of tritium will cause some initial burning in such a cylinder. Instead of trying to assess probabilities that a deuterium cylinder will burn, it is felt better to summarize here the idealized calculations so far made. The general status of the deuterium super, of the March tests, and of the physics of mixed fission-fusion devices is briefly presented in the body of this report, while some information on details--particularly of the 1951 initiator--is available in the appendices.

2. PLAN AND PURPOSE OF THE TEST PROGRAM

Thermonuclear weapons were given a new look in February 1950. At that time, a review was made of the means to get bombs with yields of the order of a thousand times that of conventional fission weapons. [redacted] b3

Tritium is very expensive, one kilogram costing the same number of Hanford neutrons as 80 kg of plutonium. Nevertheless, it appeared that the cost of tritium to ignite a Super might not be many times greater than the cost of active material in an ordinary fission weapon. This circumstance, plus the relatively low cost of ton-amounts of deuterium, led to the decision to work intensively on the problem of deuterium ignition.

It was decided that one should gain experience with small amounts of deuterium-tritium mixtures (a) as an intermediate step towards design of the full deuterium Super, if that should prove feasible, and (b) as means to test many of the unknowns in thermonuclear weapons in general.

[redacted]

Test of an initiator is urgent for the following reasons:

(a) If combined calculations on the burning of deuterium are favorable actual development of the final model will become the bottleneck. In this case a completed and tested initiator will shorten the total time required.

(b) A test may dispel doubts about mixing, unexpected electromagnetic phenomena and other unforeseen effects. On the other hand a basic weakness of the program may be discovered.

(c) Designs of thermonuclear weapons different from the deuterium Super might use a similar initiator.

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The third type of intermediate thermonuclear reaction, designed and developed to the point where it could be tested in March 1951, is the "fission booster" (Figure 3). This device is quite distinct from the DT booster previously mentioned, which jacks up the output of the fuse train to a high level with the aim of igniting pure deuterium. The fission booster also consists of DT but is placed <u>within</u> the fission bomb. There any combustion of the DT which takes place supplies 14-mev

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neutrons to the fission bomb itself, thereby increasing the efficiency and total yield of the fission reaction.

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3. SUMMARY OF CALCULATIONS ON DEUTERIUM IGNITION

Many calculations have been made in this laboratory on burning of D-T mixtures and of pure deuterium. In all cases the situations are highly idealized in geometry or in treatment of relevant physical phenomena, or in both compared to the ultimate design which one wants to evaluate. For this reason it is appropriate here to summarize past calculations and to put their results into some kind of perspective with each other and with the ultimate problem.

To begin with, it is appropriate to review the totality of physical effects which must be taken into account in any complete analysis of deuterium burning, and to indicate for each the state of our knowledge of the basis physical principles. Some of the effects are local in the sense that their importance at a given point in the medium depends only on density and temperature at that point, and others are space effects which depend upon the geometry of the configuration. In the first class belong nuclear reaction rates and rates of emission of deceleration radiation. In the second group belong hydrodynamics, thermal conduction, inelastic collision of electrons with photons created at other points in the medium, and deposition of energy at one place by particles created at another place. (The following rather technical section on the relevant physical processes, which is single-spaced, may well be omitted on a first reading.)

The two fundamental reactions in deuterium burning are the combination of two deuterons to form—with roughly equal probabilities—either a proton and a triton or a neutron and He^3 nucleus; and the reaction of a deuteron with a triton to form an alpha particle and a 14 mev neutron. Tritium burns quickly because the DT cross section is roughly 100 times greater than the DD cross section. About the precise values of the cross sections, considerably uncertainty has existed, and the values used in burning computations have depended upon the current states of the continuing experimental work. Appendix III gives curves for the product of cross section and particle velocity, averaged over a Maxwellian distribution of velocities of deuterons and tritons. The curves used at different times are shown. One sees that both DD and DT cross sections used in computations before 1950 were much higher than what is indicated by early 1950 experimental results. However, the 30 August 1950 results of T. Bonner, summarized in an addendum to Appendix III, are almost twice as high as the early 1950 curves, and even significantly higher than the pre-1950 values. The reaction rates calculated from these very recent measurements are shown in the "August 1950" curve of Appendix III. In the calculations reviewed below one should assume that the pre-1950 cross sections were used unless the calculations were made in 1950, in which case the pessimistic values were employed. The latest values have not been used in any of the computations.

Emission of deceleration radiation in the passage of electrons through the field of force of atomic nuclei is an effect which depends upon the most straightforward and well tested parts of the quantum theory of radiation. This effect and its thermodynamic inverse give a rate of exchange of energy between a Maxwellian distribution of electrons and a Planck distribution of radiation which was calculated by Hurwitz in LA-553. A slight algebraic error in this work has been corrected by Liberman (Appendix IV) who gives curves from which one can get the desired rate of exchange of energy for any set of values of the two quantities, the temperature of the radiation field and the temperature of the electrons. The correction to the work of Hurwitz shows up only when the radiation temperature is higher than the electron temperature.

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Electrons can be caused to radiate not only by acceleration in the field of force of an atomic nucleus but also by deflection in a sufficiently strong magnetic field of the order of 10^8 gauss. If sufficient magnetic fields should be developed in a thermonuclear device, for example by a mechanism analogous to the unknown reasons which cause sunspots, then the theory of the operation of the device would have to be amended, not only as regards rate of exchange of energy between electrons and radiation but also in respect to distances traveled by charged reaction products before depositing their energy. A more detailed discussion of the effect of very strong fields is given in Appendix VI along with some comments on the possibility that such fields may develop in very highly ionized material. No definitive conclusions can now be drawn on this point, which would therefore seem to deserve further investigation. The working hypothesis presently adopted in this Laboratory is this: that since the fields that would be needed are so great, the probability that they will come into existence is small enough to be neglected.

An additional disturbing local effect has not been included in any of the calculations so far and is not planned for the calculations in the near future. This effect is the irregular, turbulent mixing which is expected to take place whenever hot and light materials push heavier and colder materials ahead of them. This effect had been discussed for many years by the name of Taylor instability. [redacted]

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Among factors which are non-local and which depend upon the geometry of the configuration, one of the most important is the transport of energy from a reactive region to a colder region by 14 mev neutrons. These neutrons travel on the average a considerable distance (approximately 25 cm) before they suffer a collision and begin to deposit their energy. [redacted]

b(3)

Another geometry-dependent effect is thermal conduction from hot portions of the substance to cooler portions. The theory of this effect is fairly straightforward. Consequently, the analysis of conduction in calculations made at the present time is always based on the standard theoretical treatment which is summarized for example in LA-401.

Mechanical motions caused by pressure gradients is the last non-local effect in present thermonuclear calculations and the effect by far the most complicated to treat. The theory and basic equations are simple but non-linear. Calculations to date have in practically every instance been restricted to an idealized geometry such that motion in only one space dimension needed to be considered, either a sphere or a cylinder with temperature independent of position along the axis or an infinite mass of material with physical properties dependent on one coordinate, x, and independent of the other two coordinates, y and z. In other words, one has not so far for example succeeded in giving a satisfactory treatment for such a situation as a burning wave running down a cylinder of finite diameter, with sideways disassembly occurring in the burning region and behind it. Some work is now in progress to fill in this important gap in methodology.

After this review of the physical background of deuterium and DT burning, it is appropriate to review some of the more instructive calculations made to date which may give some perspective--incomplete though it be--on the process as a whole.

The past calculations on burning of deuterium have been concerned with two rather distinct questions: (1) Will a flame propagate down an infinitely long deuterium cylinder of suitably chosen diameter, and (2) How much energy must be supplied or how much tritium must be burned to ignite deuterium. Of these two topics, the problem of ignition has been given the most attention as the simplest with which to begin.

The concept of ideal ignition temperature presented itself already in the first work done in this laboratory on thermonuclear processes.

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Frankel, Metropolis and Turkevich (hereafter designated FMT; hand calculations in LA-523, Eniac calculations in LA-525) made the first detailed attempt to treat quantitatively the ignition of a large mass of deuterium--or of DT mixture--by heating a smaller mass.

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[redacted] The negligible time assumed in the actual calculations implies a faster rate of reaction than that which corresponds to reality.

[redacted]

b3

These calculations led to the following results:

[redacted]

b3

[redacted] b3

A second set of problems was designed to be more closely related to actual conditions that might prevail during the ignition of a super bomb:

[redacted] b3

The following results were obtained in this calculation:

[redacted] b3

Consequently, it could not be concluded from these calculations that ignition of deuterium had been demonstrated.

[redacted] b3

b3

The first detailed calculations of this kind were made by Ulam and Everett (LA-1076 and LA-1124). The following assumptions were made in these calculations.

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(3) The cross sections accepted in these calculations are those indicated by the designation "Eniac" in Appendix III.

(4) The electronic and nuclear temperatures at each point of the medium were considered separately.

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(5) Charged fragments from nuclear reactions gave their energy to the electronic and to the nuclear systems in a proportion which was estimated by "judicious guesses." Allowance was made for the time interval between production of the particle and delivery of its energy and the energy of thermal agitation of electrons or nuclei and for the separation in space of point of origin and points of deposition. The geometrical location of the deposited energy was obtained by considering particles emerging at three pre-selected directions and considering the results obtained in these three cases to give an adequate representation of the whole process of energy deposition ("spoke method").

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The results of these calculations are the following (see detailed diagrams in Figure 4).

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[redacted]

The availability of the Aberdeen Eniac therefore made it appear appropriate to refine calculations of the original Ulam-Everett type.

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[redacted]

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[redacted] Other assumptions of the calculation were:

(1) The more recent, revised densities of Appendix VII.

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[redacted]

(3) Deposition of energy by charged particles was again treated as in the Ulam-Everett calculations by the spoke method.

The results of the Eniac calculations may be seen in broad outline by reference to Figure 4. [redacted] b3

It was clear from this result that it would not be useful to continue the calculations for this particular case. [redacted] b3

It was necessary to give up the Eniac for other uses at this time although it would have been interesting to follow the problem further. [redacted] b3

It is unlikely that the optimum geometrical disposition of the initially adopted amount of tritium was made in any of these problems.

The radius of the sphere which has to be spiked in this manner remains quite uncertain, and must be determined by future calculations.

It should be emphasized that the question of ignition is not a question of yes or no but simply a question of amount. It should also be noted that all amounts referred to in Figure 4 and in this discussion are calculated on the basis of normal liquid density (slightly different values being used for a standard of reference in the older and the newer calculations, as indicated in Figure 4).

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In contrast to the problem of deuterium ignition which is a matter of quantity of tritium, one has to deal with a yes or no question in the problem of propagation of a burning reaction down a cylinder of deuterium. The calculations made to date on this problem are far more idealized than those concerned with deuterium ignition and consequently one is far from being able to make any reliable forecast on this most crucial of all issues in the operability of a deuterium Super.

An early attempt was made by Hoyt and Evans in the summer of 1947 (LA-666) to determine whether a thermonuclear reaction will propagate lengthwise in an infinitely long cylinder of liquid deuterium. This calculation was based on the following picture:

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An attempt was made to determine the distribution of temperature and density in the flame front by an iterative procedure in which the results of a given stage of approximation were fed into the next stage as starting conditions. The numerical calculations were not continued beyond the 4th approximation because of inaccuracies inherent in the numerical procedures used. It was not possible to draw any definite conclusion about the convergence of the iterative procedure, and consequently it is not safe to conclude that there in fact does exist a stationary solution with the given velocity.

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It is again very difficult to draw any definite conclusions from this circumstance. However, the existence of a minimum velocity for flame propagation is exactly what is to be expected, not only from a previous more idealized calculation of Evans and Hoyt (LA-665) but also from the well-known physics of detonation of ordinary explosives.

Further insight about burning pure deuterium is given by recent and not yet completed calculations of Fermi and Ulam on another type of problem, rather idealized in character: 63

The preliminary results are presented in Table I below:

Table I

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Part of the difference may be due to the different simplifications in the hydrodynamics. It is unclear whether optimistic or pessimistic simplifications are more important in the Fermi-Ulam calculations.

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[redacted] It is of course clear that the results of such calculations for an infinitely long cylinder can be taken over approximately to the case of a sector of the cylinder of length sufficiently greater than the diameter. [redacted]

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4. COMPRESSION OF THE DEUTERIUM AND OF THE DT WHICH IS TO IGNITE IT.

In the foregoing discussion, it has been noted that the amount of tritium needed for ignition varies inversely as the square of the density at which this fuel is used, provided that both the DT and the surrounding deuterium are compressed by the same amount. This simple connection between density and amount of tritium needed is a practically rigorous relation dependent on a similarity law, provided that one looks apart from the effect of the walls and the HE in contributing to the inverse Compton effect.

Practically nothing has so far been done to investigate means of imploding a liquid hydrogen charge which would leave open to outer space a substantial fraction of the surface of the thus assembled thermonuclear reactant. Neither is it yet known how deleterious would be the effect of walls of a material of such a low effective atomic number as HE, even if these walls should completely surround the charge at the moment of thermonuclear ignition. Both problems are important and deserve thorough investigation.

[redacted] b3

More refined calculations on the compressibility of deuterium are in progress. A significant point at issue is the degree of dissociation of the deuterium at high temperatures and pressures.

An experimental program is under consideration, aimed at the verification of the equation of state of deuterium. The first step in that program will consist of sending plane shock waves into liquid deuterium and in exploring the behavior of these shock waves in liquid deuterium by photographic methods and by electric contacts which are closed by the shock (pin technique). [redacted] b3

In order to carry out this program, a considerable effort in development of low-temperature techniques is required. This involves large increases in liquefaction facilities and development of large and peculiarly shaped dewar vessels and related low-temperature procedures.

The plan for increases in liquefaction facilities is shown in the following table:

Table 2

Liquefaction Facilities Planned
(Capacities in liters per hour)

Location	Liquid H_2 or D_2	Liquid Nitrogen or Air	Liquid Helium
1. Present Los Alamos Capacity	30	30	4
2. Additional LASL Capacity (to be constructed within a year)	30 - 60	75	20 (?)
3. Eniwetok (for Spring 1951 tests)	30 - 60	50	
4. Test Site (for 1952 tests)	200 - 350	200	
5. New Cryogenic Laboratory (within 500 miles of LASL) (available by 1952)	200 - 350	200	

A plan for a new cryogenic laboratory to be built within 500 miles of Los Alamos is now under consideration. This laboratory would be responsible for the development of dewar vessels and liquefaction and storage techniques. Research on the pertinent properties of deuterium is under way at LASL and at the Ohio State Research Foundation. For further details, see Appendix IX.

5. MIXED FISSION-FUSION REACTION

The mixed fission-fusion gadgets utilize the <u>neutrons</u> produced in the thermonuclear reaction more than the <u>energy</u> released in that reaction. Indeed, if thermonuclear fuel is surrounded by fissionable material, the neutrons produced in the thermonuclear reaction will cause fission and release much more energy than that given out in the thermonuclear reaction itself. Two devices have been proposed which would utilize this principle. [redacted] b3

The implosion system used for the booster is similar to that of TX-5. The efficiency expected for the booster is approximately the same as for TX-5, probably somewhat less than TX-5. This is due to the near-cancellation of two effects:

[redacted] b3

The present model of the fission booster has not been designed for an optimum use of the booster bomb as a weapon, but has been planned as an experiment. The objectives of a booster test would be to determine:

(1) The extent to which the thermonuclear reaction occurs.

(2) The rate at which the DT burns.

(3) The initial conditions at which the DT ignites.

[redacted] b3

Measurements such as described in Appendix II, if made on a test shot of a fission booster, would provide fairly direct answers for objectives (1) and (2) but would provide only indirect information about the initial conditions for DT ignition. [redacted] b3 [redacted] However, limitations on fissionable material, on laboratory effort, and particularly on supply to Eniwetok, have indicated that only one of these devices should be tested. [redacted]

The booster principle may be applicable under some conditions in producing more effective bombs. [redacted]

The second mixed fission-fusion method which has been discussed is the alarm clock. [redacted]

[redacted]

Detailed calculations on the alarm clock were carried out in 1947 (LA-636, LA-645, LA-648). [redacted] Such an objection does not seem to be well founded, at least as far as the radioactive effects on the immediate neighborhood of an air burst are concerned. In fact, the only arguments which can be advanced in the present state of our knowledge in connection with such an air burst are arguments based on scaling from fission bombs.

[redacted]

In addition, during the last two months, a modified, and more hopeful, alarm clock has received some attention. [redacted]

Of

course the expense of the tritium might well favor ignition by a simple fission bomb.

Calculations on this modified alarm clock are still in a very preliminary state, and specific models being examined are tentative. b3

[redacted]

The present Los Alamos program of intermediate thermonuclear tests has some close tie-ins with alarm clock development which should be of value if this line of big bomb development should be followed at some future time:

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[redacted]

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D3

Considerations of the progress of the DT burning and on the proper design of the radiation valve are also given in Appendix XIV.

Attempts are being made to refine the calculations to increase the assurance of operability and to permit the most intelligent design of the measuring equipment for the March 1951 tests.

It was impossible to carry the design on such a device far enough before freezing of the plans for the 1951 tests made it necessary to exclude this change. Nevertheless, considerable thought has been given to some features of the propagation of a flame front down the DT cylinder of a diameter which is at the same time large enough to make sidewise hydrodynamics negligible and yet small enough to permit the escape of radiation. An interesting by-product of this analysis (Appendix XV) is a relation between the stability of a DT mixture at a given temperature and density and the dispersion of the velocity of sound in this mixture.

The more detailed calculations already made, as well as the numerical computations now being set up, are concerned with these points:

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[redacted] This latter point should yield information as to the size of the fission bomb required to ignite the DT (DINEX).

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[redacted]

(See Appendix II for more details on the program of measurements.)

8. ASSESSMENT OF MILITARY VALUE

In the present state of knowledge it is impossible to make a valid statement about the relative merits of the various types of fission and fusion bombs. We do not know how expensive, how big, and how efficient a fusion bomb will be. In addition, we do not know in sufficient detail the effects of a fusion bomb. Finally, we cannot foresee the military situations in which fission and fusion bombs, respectively, are the more appropriate. Nevertheless, we make an attempt below in Table 3 to summarize the effects and compare the values of the various types of bombs. It is believed that such a table will be useful in order to compare the various types of bombs and to allow one to decide which one is best for which purpose. One must remember that such an over-all picture is always misleading if one believes in its details.

In constructing the table assumptions will have to be made concerning the relative value of the various materials used in the bombs. These values change as the methods and capacities of production alter. At present, it seemed best to use the following equivalents:

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Values in Table 3 are expressed in this basis in equivalent kilograms of plutonium. This value appears in Column 7.

The simplest method of comparing the value of bombs is the so-called "figure of merit." This figure of merit is obtained by taking the conventional figure for area destroyed by blast (which is proportional to the two-thirds power of the yield) and dividing it by the value of materials contained in the bomb, expressed in equivalent kilograms of plutonium. The usual statement is that the greatest figure of merit corresponds to the most economical use of the material. This figure of merit appears in Column 11. This figure of merit, however, is misleading for several reasons. First, the efficiencies entering into the figure of merit are uncertain in all cases listed. Second, it is blithely assumed that it is as important to destroy a circle of a hundred square miles area as to destroy twenty circles of 5 square miles. Finally, it is assumed that the area destroyed is proportional to the two-thirds power of the yield of the bomb. This is a reasonably valid assumption for the smaller bombs considered. For the larger bombs this figure must be changed for two opposite reasons. First, for these larger bombs radiation is likely to destroy a greater area than shock, and the shock of radiation increases with the first power of the yield rather than with the two-thirds power. To correct for this effect would increase the calculated figure of merit of the thermonuclear and alarm clock bombs listed under II and III in the Table. It must be remembered, however, that radiation effects are not as well explored as shock effects; in particular, cloud coverage or condensation due to the shock wave of the bomb may effectively decrease the damage area due to radiation.

An opposite effect must be taken into account for the larger thermonuclear bombs under II (b) and II (c). For these bombs the area damaged by shock will be less than indicated by the two-thirds power law and therefore one can argue that from the point of view of shock damage the "figure of merit" should be smaller than given in the Table. The reason is that these large bombs will locally lift out the top of the atmosphere. Sidewise propagation of the shock will therefore be limited. For this reason it is strongly urged to place little weight on the figures of merit, and rather to use the last columns in the Table in evaluating the relative usefulness of the various bombs for specific purposes. In addition to the data given in Table 3, one should also consider the radiological effects of the various bombs. Assessment of these radiological effects was omitted because too little is known about the radioactive fall-out and about the resultant contamination. It is expected that radioactive contamination can be minimized in sufficiently high air bursts. It is completely unknown how strong a radioactive contamination can be produced in surface bursts.

One cannot construct a table which is useful for a rough evaluation without giving the impression of precise knowledge which we unfortunately do not possess. In using Table 3 one should therefore always put in the proper amount of critical doubt.

9. CONCLUSION

On burning of pure deuterium, the great outstanding theoretical issue is to find out whether a flame will propagate down an infinitely long deuterium cylinder. Of the experimentally determinable factors in the physics of burning, one possesses a knowledge which--subject to further improvement--probably will suffice to permit a definitive answer to this question. The problem is primarily one of theory. The calculations can and must be pushed through to a clear-cut conclusion.

For the short-range, the intermediate thermonuclear test of March 1951 will represent a real step forward if the measurements disclose burning to be taking place nearly as expected. In that case, the door will be opened to the possibility of a future intermediate test on a more extensive scale. Whether one will want to make such a test will depend upon, among other factors, one's views on the feasibility of a thermonuclear weapon. If the feasibility and attractiveness are sufficiently clear, one may prefer not to use up any tritium in a further intermediate experiment in order to advance as much as possible the date of the full-scale test. On the other hand, if such an intermediate experiment is decided upon for any one of a variety of reasons, the nature of that experiment will probably depend very considerably upon the nature of the ultimate thermonuclear weapon. In this respect the experiment would appear to be quite in contrast to the March 1951 test, which is partly a test of the physics of thermonuclear reactions and partly a test of the first step of an ignition process applicable to almost any kind of thermonuclear weapon now foreseen. But the next stages of the ignition process--and therefore probably also the design of any subsequent intermediate experiment--would have to be adapted to the direction in which one is going.

If on the other hand the 1951 test is quite discouraging or if calculations performed in the meantime disclose great and unexpected difficulties, one will probably delay any future thermonuclear tests until some new factors or new ideas give rise to added reason for hope.